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Stress and Deformation Analyses of Twin-Spirals Scroll Plates Based on CAE

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ABSTRACT

On the basis of the elastic mechanics theories, heat transfer theories, and CAE, the non-uniform temperature distribution was studied, Mises stress and deformation distribution of 3D twin-spirals scroll plates was presented. The Mises stress and deformation of scroll plates induced by non-uniform temperature field and gas pressure was investigated. Orbiting and fixed scrolls were engaged with each other and the Maximum Mises stress and deformation of scroll plates analyses were performed under different axial and radial gap at the crank angle that the Maximum compression ratio happens. On the basis of calculated results using CAE, the suitable gap value for twin-spirals scroll plates design was presented, which provided useful data for developing the high-performance twin-spirals scroll compressor.

1 INTRODUCTION

In recent years, protecting environment and reducing energy consumption become two big problems for the human being. In order to economize energy sources, many researchers concentrate on lessening machinery energy consumption, cutting down driving force spoilage, and gaining better power characteristic. As a kind of new efficient positive replacement, scroll compressor has many advantages such as simple structure, high-efficiency, low noise, high reliability, low vibration, light weight, and small size compared with other types of compressors. It is becoming popular and widely used in refrigeration, air-conditioning, various kinds of gas compression, and pressurized pump products, etc. At present with the wide application of the scroll compressor, its outstanding advantages have attracted the attention of a lot of countries. With the development of scroll compressor to bigger displacement and power, the advantages of scroll compressor employing twin-spirals, such as increasing the displacement and reducing the diameter of scroll plate, have gotten increasingly approbation, at the same time it requires higher quality products, superior reliability, optimization structure, and better performance in an even shorter delivery time. However it is not easy as their key parts-orbiting and fixed scroll have complex shape, high precision, and the appropriate axial and radial gap requirement. For twin-spirals scroll compressor, compressed gas will inevitably produce heat and pressure. It causes stress and deformation of the scroll wrap and influences the scrolls gap. The stress, deformation, and gap significantly affect efficiency of twin-spirals scroll compressor. So an accurate pressure and temperature distribution on twin-spirals plates must be obtained. The stress and deformation analyses of scrolls induced by non-uniform temperature field and gas pressure will be investigated. The stress and deformation analyses results after scrolls engage with each other can help us get the suitable gap value.

2 PRESSURE AND TEMPERATURE DISTRIBUTION

2.1 The Working Principle of Twin-Spirals Scroll Compressor

The working principle of twin-spirals scroll compressor is shown in *Figure 1*. There both have two scroll wraps at orbiting and fixed plate. One of the scroll plates is fixed and the other orbiting scroll around the centre of the fixed scroll wrap. The orbiting scroll is driven by a simple short-throw crank mechanism. The contact points between the twin-spirals wraps are shifted along the spiral curve. The relative angle of the two scroll plates are maintained by

means of an anti-rotation coupling mechanism located between the back of orbiting scroll plate and the frame. When the angle reached suction angle θ_s , suction chamber closed, then reached the Maximum, crescent-shaped suction chamber ① in Figure1 (a) formed. Volume of crescent-shaped suction chamber decreased when it moved to the centre with the clockwise, thus it realized gas compression as illustrated in Figure1 (b), (c), (d), (e) and (f). In twin-spirals scroll compressor, four suction chambers - ①, ②, ③ and ④ formed every crank rotating 2π . Each suction chamber volume is same. Closed time interval of two adjacent chambers is $\pi/2$. There have two kinds of compression process. The one kind of compression process is ① and ③ formed between the inner orbiting scroll wrap and the outer fixed scroll wrap. The other kind of compression process is ② and ④ formed between the outer orbiting scroll wrap and the inner fixed scroll wrap. Four exhaust chambers formed at the same time in each round (2π), and the beginning exhaust time interval of two adjacent exhaust chambers is also $\pi/2$. Although the compression process and the formation time are different for four suction chambers, the pressure change process is same, phase difference of two adjacent chambers pressure change is $\pi/2$. So it is different from single-spiral scroll compressor. For single-spiral scroll compressor, two symmetry working chambers realize suction, compression and exhaust at the same time. But for twin-spirals scroll compressor, four working chambers realize suction, compression and exhaust one by one, so it has lower exhaust losses and the flow pulsation.

2.2 The Basic Parameters of Twin-Spirals Wrap

Table 1 is the basic parameters of twin-spirals wrap. Figure2 is 3D analyses model construction of orbiting and fixed plate. In order to increase the exhaust space, reduce exhaust pulsation and resistance, the centre part of scrolls wrap was directly cut.

Table 1: The Basic Parameters of Twin-Spirals Wrap

The Parameters	Value
Scroll Wrap Type	Twin-Spirals Evolutes
Media	Air
The Radius of Basic Circle	7.63944mm
Orbit Radius	7.5mm
The Thickness of Scroll Wrap	4.5mm
The Height of Scroll Wrap	50mm
Suction Pressure	0.086MPa(Absolute Pressure)
Suction Temperature	20 °C

2.3 Pressure and Temperature

The working condition of twin-spirals scroll compressor is divided into suction, compression and exhaust process. The working chambers are also divided into suction, compression and exhaust chamber, as shown in Figure3. 1、6、7 and 10 are suction chamber, 2、3、4、5 and 9 are compression chamber, 8 is exhaust chamber. Meanwhile, in order to balance the axial gas pressure, the back pressure chamber is set, reasonable back pressure chamber can reduce the axial wear and improve stability of twin-spirals scroll compressor.

The temperature distribution of chambers gradually reduces from the center of scrolls to the outer circle. The temperature of working chambers and back pressure chamber are not same, showing non-uniform state. The pressure and temperature distribution are gotten through theory analyses and experiment test. The force of twin-spirals scroll plates changes with the crank angle. The most adverse circumstance is the beginning exhaust moment. The Maximum Mises stress and deformation can be gotten. In imposing the load, scroll wrap is divided into different parts according to different pressure, it guarantees the independence of different parts. The loading value and position are decided by the dynamics model. According to testing results and heat analyses, the temperature distribution is gotten. The software analyses and practical test are used to ensure the validity of temperature field. 5 radial points and 6 ring points, total 30 points temperature are tested, and the test results and generated results by the software are compared, the deviation of two kinds of methods is under 1.5°C , so the results(Figure6-a) generated by the software fully can used for CAE.

3 STRESS AND DEFORMATION ANALYSES

3.1 Meshed Twin-Spirals Scroll Plates

Meshed twin-spirals scroll plates are shown in *Figure4* (orbiting scroll plate nodes: 15911, fixed scroll plate nodes: 21627). Through analyses, the node number of scroll plates is suitable for CAE.

3.2 Material Properties of Scroll Plates

In designing twin-spirals scroll compressor, considering the large displacement, structural characteristics, and machine quality, Aluminum Alloy is applied to replace Ductile Cast Iron. The detailed material properties are shown in *Table 2*. Expansion coefficient of Aluminum Alloy is 2 times than Ductile Cast Iron, it will lead to greater deformation under the same temperature field. It greatly affects the engaging gap of orbiting and fixed scroll. Interference is also easy to happen, but the quality reduces almost 2/3, which helps big displacement of twin-spirals scroll plate, but glue is more likely to happen for Aluminum Alloy in the high temperature. It should be considered in scroll plates design and analyses.

Table 2: Material Properties

Material Properties	Ductile Cast Iron	Aluminum Alloy
Elasticity Modulus E	173GPa	70GPa
Poisson Ratio μ	0.3	0.3
Density ρ	$7.8 \times 10^{-6} \text{ kg/mm}^3$	$2.7 \times 10^{-6} \text{ kg/mm}^3$
Expansion Coefficient α	$1.33 \times 10^{-5} / ^\circ\text{C}$	$2.36 \times 10^{-5} / ^\circ\text{C}$
Heat Transfer Coefficient λ	$0.0526 \text{ W/mm} \cdot ^\circ\text{C}$	$0.1325 \text{ W/mm} \cdot ^\circ\text{C}$
Specific Heat c	$500 \text{ J/kg} \cdot ^\circ\text{C}$	$126 \text{ J/kg} \cdot ^\circ\text{C}$
Tensile Strength δ_b	400MPa	340MPa
Fatigue Strength δ_{-1}	270MPa	275MPa

3.3 Boundary Conditions and Constraints

3.3.1 Boundary Conditions

The following boundary conditions are assumed before CAE.

- Under a steady state, the parameters of scroll plates at any given point are constant. No heat is transferred between orbiting and fixed scroll. No heat is transferred between the scrolls and the external environment, so the scrolls are adiabatic.
- Pressure is constant in vertical direction of scroll plates (Z axis). Everywhere pressure is constant in the same chamber. Pressure changes in X-Y plate according to changed crank angle.

3.3.2 Constraints

Some constrains are applied to the Mises stress and deformation analyses according to the operation situation of real twin-spirals scroll compressor.

For fixed scroll: The freedoms in the X、Y and Z axis in the surface connected with frame are completely constrained.

For orbiting scroll:

- The freedom in the Z axis in the surface contacted with frame is constrained.
- The self-rotation of Z axis in the orbiting scroll connected with anti-rotation cranks is constrained.
- The freedoms in the X and Y axis in the inner bearing contacted with crank are constrained.

3.4 Mises Stress and Deformation Analyses of Orbiting Scroll

3.4.1 Gas Pressure Action

Figure5 is Mises stress and deformation distribution of orbiting scroll induced by gas pressure. The analyses results indicate that the Maximum Mises stress and deformation are small under gas pressure action. The Maximum Mises

stress 5.575MPa appears at the end of the second circle of scroll wrap. It is caused by different pressure between inner and outer of scroll wrap. Because the back pressure of Z axis, the Z axis deformation is smaller than radial. The Maximum deformation 0.0105mm also appears at the second circle scroll wrap. So the deformation caused by gas pressure has a little effect for axis and radial gap leakage.

3.4.2 Temperature Field Action

Figure6 is Mises stress and deformation distribution of orbiting scroll induced by temperature field. Temperature field reduced from the inside to outside of scroll plate. The Maximum temperature appears at the center wrap of exhaust chamber. The Maximum temperature difference is 50°C . Mises stress and deformation caused by temperature field are larger a magnitude than the gas pressure. The Maximum total deformation reaches 0.0792mm happened at scroll wrap roof of exhaust chamber, which is mainly due to the Z axis deformation results. The Maximum Mises stress is 94.677MPa happened at under floor of exhaust chamber near the wrap root, which is caused by thermal stress. As a result of high stress and large deformation induced by temperature field, axial and radial deformation become the biggest factors for axial and radial leakage, especially high-pressure gas leakage in exhaust chamber, but it can improve leakage through the top wrap modify.

3.4.3 Coupling Action of Gas Pressure and Temperature Field

Figure7 is Mises stress and deformation distribution of orbiting scroll under coupling action of gas pressure and temperature field. Mises Stress and deformation distribution are similar to the simple temperature field action. It just has a little increase, which also shows the absolute advantage impact of temperature field, so controlling exhaust temperature is the most critical and most direct route to control the Maximum Mises stress and deformation.

3.5 Mises Stress and Deformation Analyses of Fixed Scroll

Figure8 is Mises stress and deformation distribution of fixed scroll under coupling action of gas pressure and temperature field. Z axis deformation of fixed scroll has a large difference compared with orbiting scroll. The deformation directions of orbiting scroll caused by gas pressure and temperature field are opposite, but for the fixed scroll, they are same. Because no back pressure acts on fixed scroll, Z axis the Maximum deformation 0.0876mm of fixed scroll is larger than the Maximum deformation 0.0791mm of orbiting scroll. Same with orbiting scroll, the Maximum deformation appears at scroll wrap top of exhaust chamber. It has the near same Mises stress distribution with the orbiting scroll, the Maximum Mises stress appears at exhaust vent, in part because of high temperature and the stress concentration of exhaust vent.

3.6 The Axial Gap and Radial Gap Analyses

3.6.1 Mises Stress and Deformation Distribution of Scrolls Engaged with Each Other in the Minimum Gap Situation

Figure9 is Mises stress and deformation distribution of scrolls engaged with each other in the Minimum gap situation under coupling action of gas pressure and temperature field. The deformation distribution of X, Y and Z are similar to the results of single fixed scroll. The Maximum total deformation is 0.0943mm , also appears at scroll wrap top of exhaust chamber. But the Maximum Mises stress reaches 299MPa , appears at scrolls engaging surface of exhaust chamber, and is more than Fatigue strength, which is due to scrolls wrap interference caused by the inconsistency of deformation direction and value.

3.6.2 Mises Stress and Deformation Distribution of Scrolls Engaged with Each Other in the Critical Gap Situation

Figure10 is Mises stress and deformation distribution of scrolls engaged with each other in the critical gap situation under coupling action of gas pressure and temperature field. The deformation and Mises stress distribution are similar to the results of single fixed and orbiting scroll. Safety factor is 2.8; it can meet the design requirement.

3.6.3 Axial and Radial Gap VS the Maximum Mises Stress and Deformation of Scrolls Engaged with Each Other

Figure11 is axial and radial gap vs. the Maximum Mises stress and deformation of scrolls engaged with each other. For fixed axial gap $\delta_a = 0.025\text{mm}$, when radial gap increases from 0, Mises stress and deformation gradually reduce. Small radial gap causes mutual interference and big Mises stress of scrolls, but deformation has a little change in the whole process. When radial gap reaches 0.03mm , if continue to increase, Mises stress and deformation have very

small change, nearly keep constant. It is because scrolls interference disappeared. For fixed radial gap $\delta_r = 0.03mm$, when axial gap increases from 0, Mises stress and deformation gradually reduce. Small axial gap causes mutual interference and big Mises stress of scrolls, but deformation also has a little change in the whole process, when axial gap reaches $0.025mm$, if continue to increase, Mises stress and deformation have very small change, nearly keep constant, it is also because scrolls interference disappeared. Conjunction with leakage model and loss model of twin-spirals scroll compressor, $\delta_a = 0.025mm$ and $\delta_r = 0.03mm$ can be as the best sealing gap value for real engineering application.

4 CONCLUSIONS

- 1) The temperature field declines from the center of scrolls to the outer circle.
- 2) The Maximum Mises Stress and deformation caused by temperature field are larger a magnitude than caused by gas pressure.
- 3) The Maximum deformation of the orbiting scroll induced by temperature field and gas pressure is $0.0794mm$, appears at scroll wrap top of exhaust chamber. The Maximum deformation of the fixed scroll is $0.0903mm$; large deformation mainly appears at scroll wrap top area of exhaust chamber.
- 4) The Maximum Mises stress of the orbiting scroll induced by temperature field and gas pressure is $95.431MPa$, and that of the fixed scroll is $90.451 MPa$, appears at scroll wrap root of exhaust chamber.
- 5) The Maximum Mises stress and deformation of scrolls engaged with each other in the critical gap situation induced by temperature field and gas pressure are $97.288Mpa$ and $0.0886mm$, appear at exhaust vent.
- 6) The best sealing gap value $\delta_a = 0.025mm$ and $\delta_r = 0.03mm$ are gotten.

The calculated results provide useful data for the optimization design of scroll mechanism.

REFERENCES

- [1] Guirong Du, Tao Liu, Boxian Qiu, et al. The F.E.M. Analysis of Shell of Scroll Compressor. In: Proc. of the 2001' International Compressor Technique Conference. Sponsored by Xi'an Jiaotong University, Xi'an, China. 2001: 248-253.
- [2] Jin Dan Chen Xu Tian Tao. Stress and Deformation Analysis of Orbiting Scroll in Scroll Compressor under Inhomogeneous Temperature Field [J]. Fluid Machinery, 2003, 6 (31): 11-14.
- [3] ZHAO Shufeng; CHEN Xu; TIAN Tao. Analyses of Stress and Deformation of the Orbiting Scroll of a Scroll Compressor [J]. Chemical Engineering & Machinery, 2003, 30(1): 17-20.
- [4] M. E. Marler, K. B. Kumar. Determination of scroll wrap contact stress using the boundary element method. In: ICECP. Purdue, USA, 1992: 1117-1125.
- [5] Eric Winandy, Claudio Saavedra O., Jean Lebrun. Experimental Analysis and Simplified Modelling of a Hermetic Scroll Refrigeration Compressor[J]. Applied Thermal Engineering, 2002, 22: 107-120.
- [6] Taichi Tateishi, Haijime Sato, Hiroyuki Kobayashi, Hisao Mizuno. Development of High Performance 3D Scroll Compressor. In: ICECP. Purdue, USA. 2006: C059.
- [7] Kwangha Suh, Daenyong Heo, Hyeongseok Kim. CAE/CFD Application for Linear Compressor. In: ICECP. Purdue, USA. 2006: C032.
- [8] Rinaldo Puff, Marcos Giovani Dropa de Bortoli, Raul Bosco, et al. The Use of CAD/CAE Tools in Compressor Development Focusing Structural Analysis. In: ICECP. Purdue, USA. 2006: C149.
- [9] Byung-Kil Yoo, Byeong-Chul Lee, Myungkyun K. Kiem, Sung-Chun Kim. Structure Design of a Scroll Compressor Using CAE Analysis. In: ICECP. Purdue, USA. 2006: C051.
- [10] Chiachin Lin, Yuchoung Chang, Kunyi Liang, Chinghua Hung. Temperature and Thermal Deformation Analysis on Scrolls of Scroll Compressor [J]. Applied Thermal Engineering, 2005, 25: 1724-1739.

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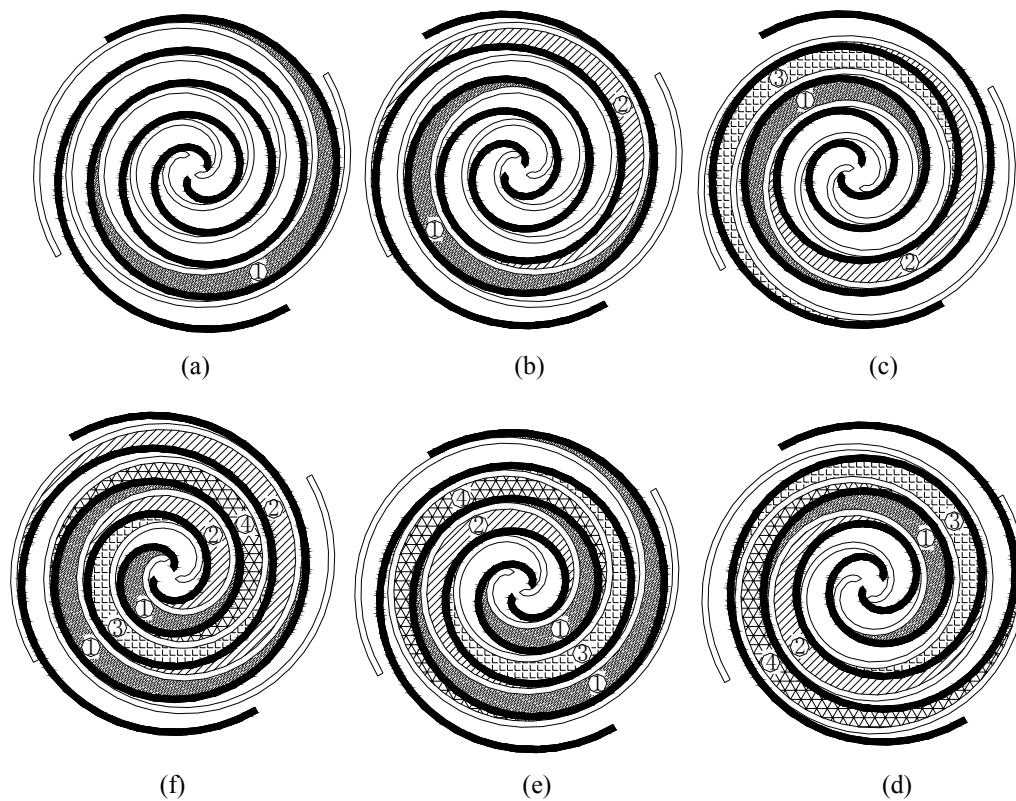


Figure1 The Working Principle of Twin-Spirals Scroll Compressor

(a) Chamber 1 Suction End (b) Chamber 2 Suction End (c) Chamber 3 Suction End (d) Chamber 4 Suction End
(e) Chamber 1 Suction End Again (f) Beginning Exhaust of the First Formed Chamber 1

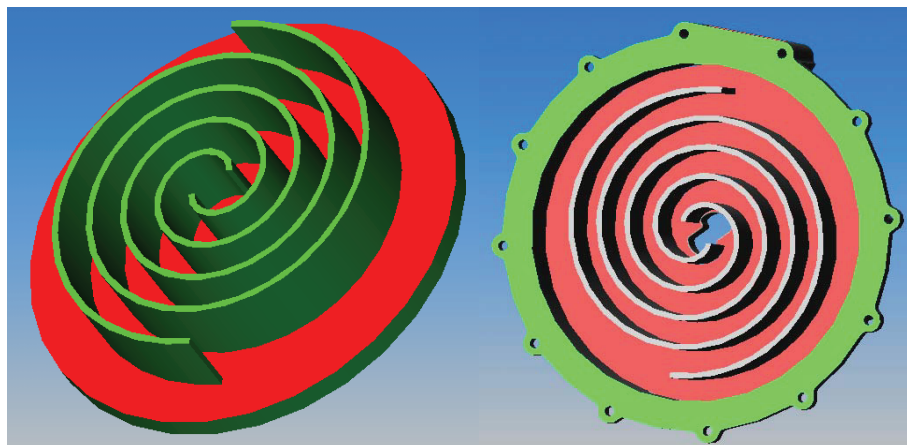


Figure2 3D Analyses Model Construction of Orbiting and Fixed Scroll

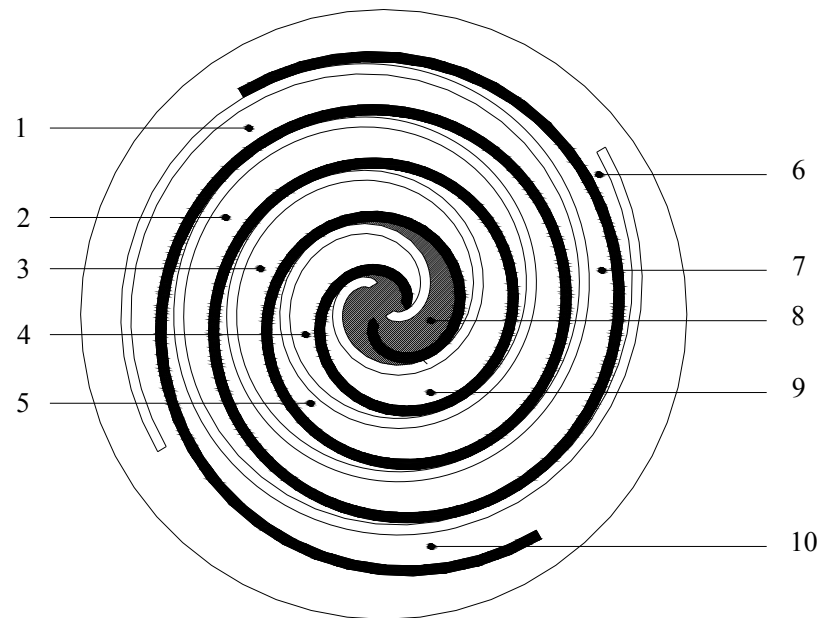


Figure 3 The Working Chambers of Twin-Spirals Scroll Compressor

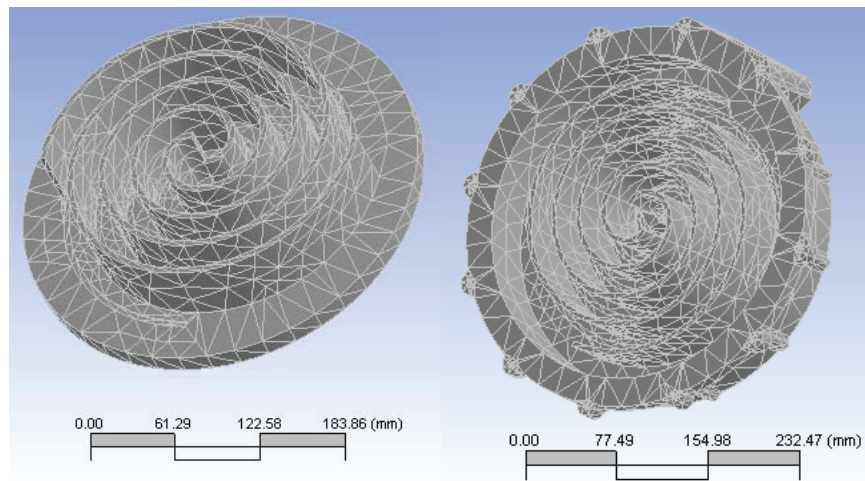


Figure 4 Meshed Twin-Spirals Scroll Plates

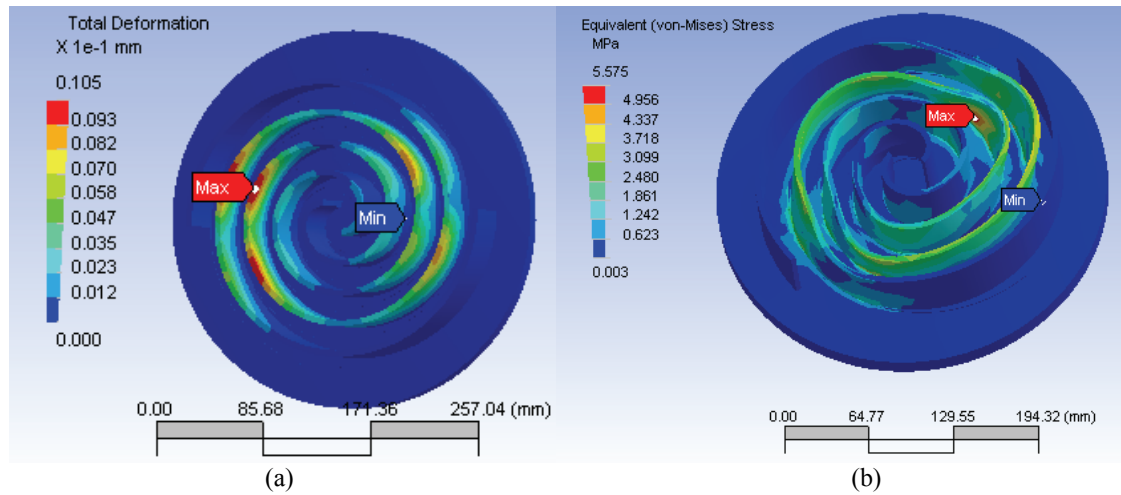


Figure5 Mises Stress and Deformation Distribution of Orbiting Scroll Induced by Gas Pressure
(a) Total Deformation Distribution (b) Mises Stress Distribution

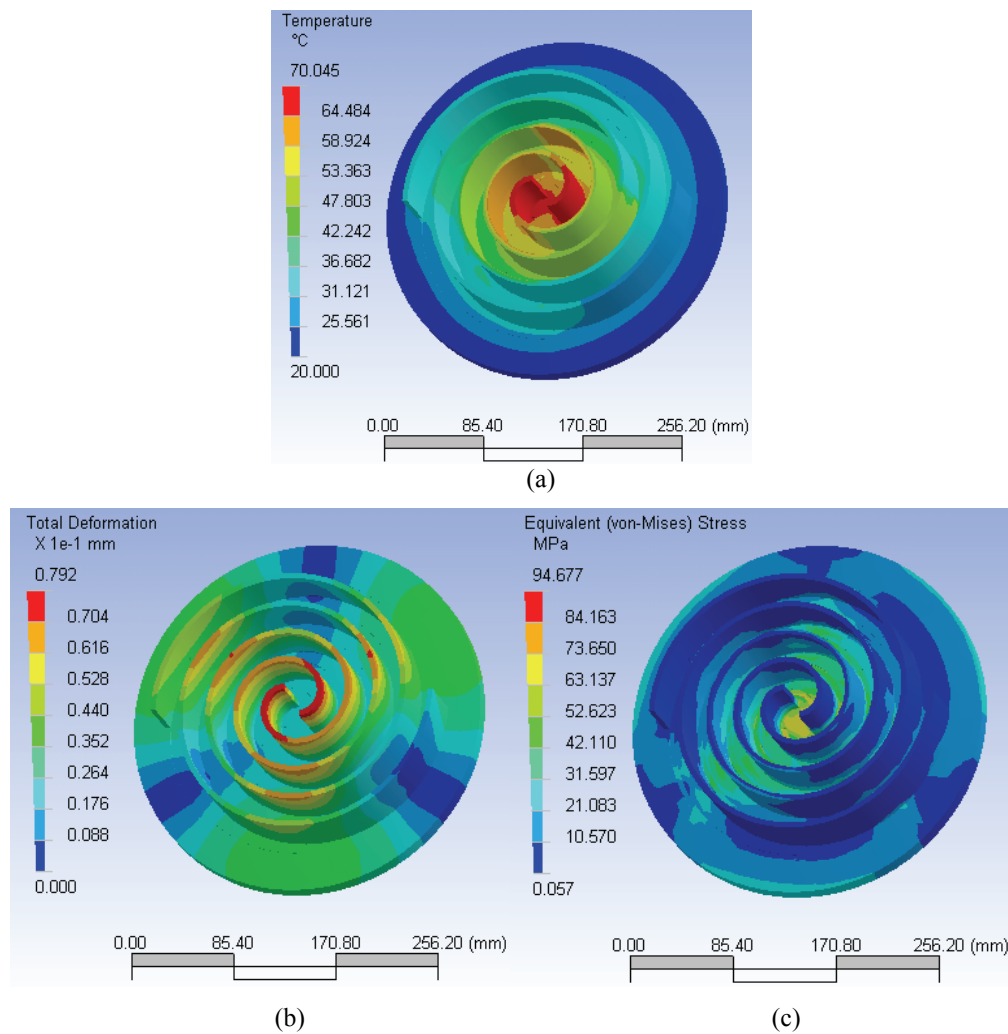


Figure6 Mises Stress and Deformation Distribution of Orbiting Scroll Induced by Temperature Field
(a) Temperature Field Distribution (b) Total Deformation Distribution (c) Mises Stress Distribution

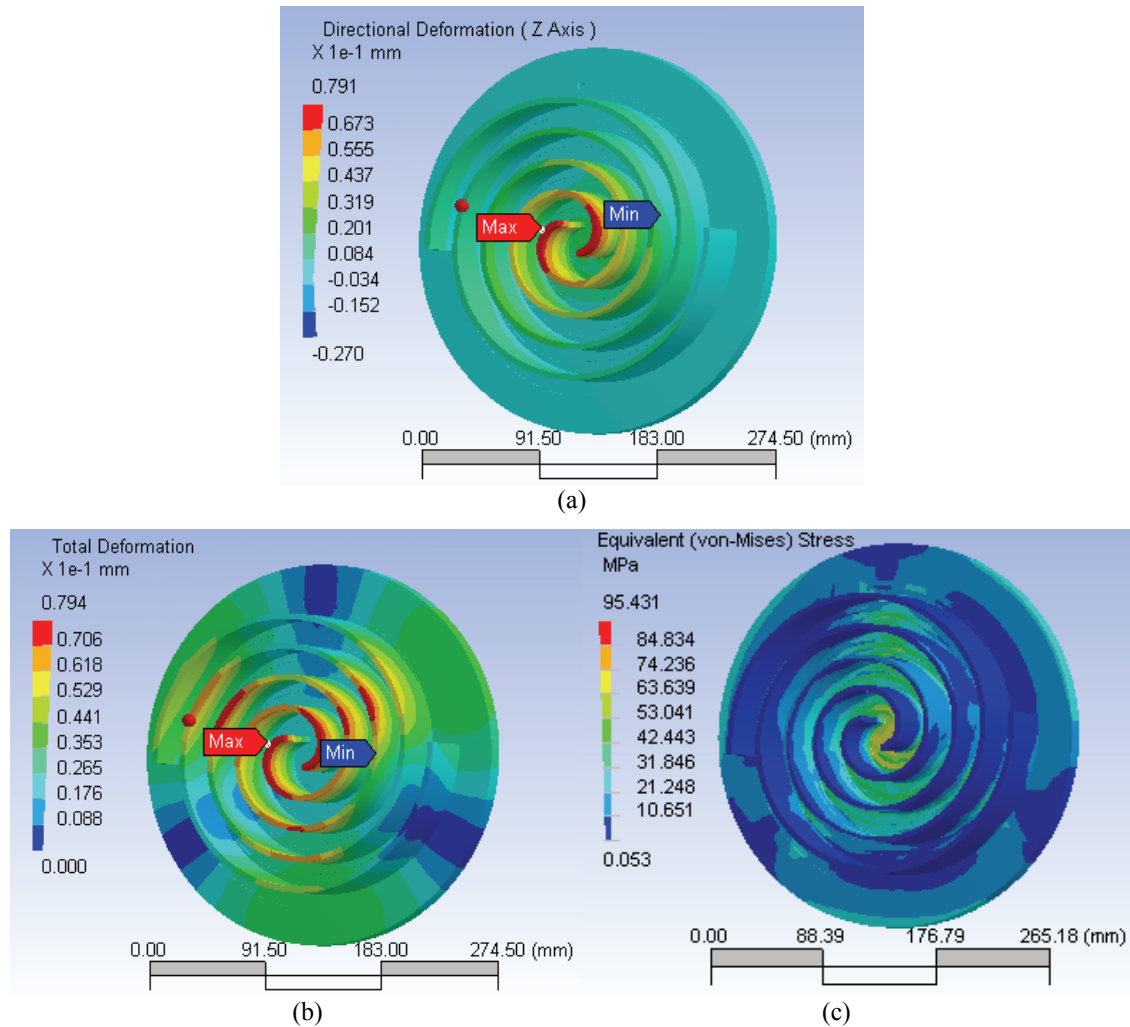
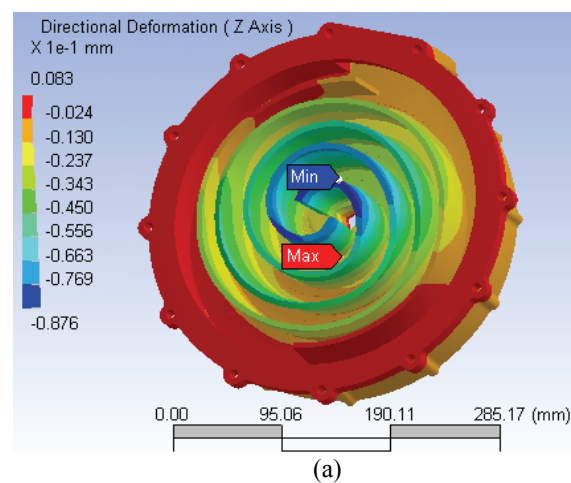


Figure7 Mises Stress and Deformation Distribution of Orbiting Scroll Induced by Gas Pressure and Temperature Field
 (a) Z Axis Deformation Distribution (b) Total Deformation Distribution (c) Mises Stress Distribution



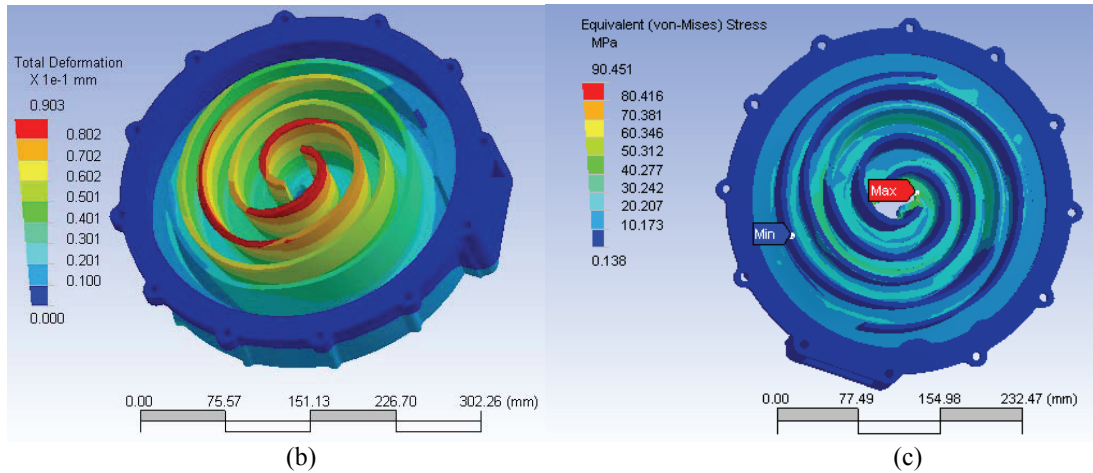
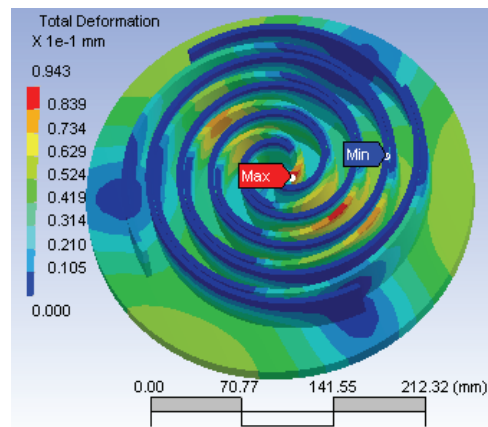


Figure8 Mises Stress and Deformation Distribution of Fixed Scroll Induced by Gas Pressure and Temperature Field
(a) Z Axis Deformation Distribution (b) Total Deformation Distribution (c) Mises Stress Distribution



(a)

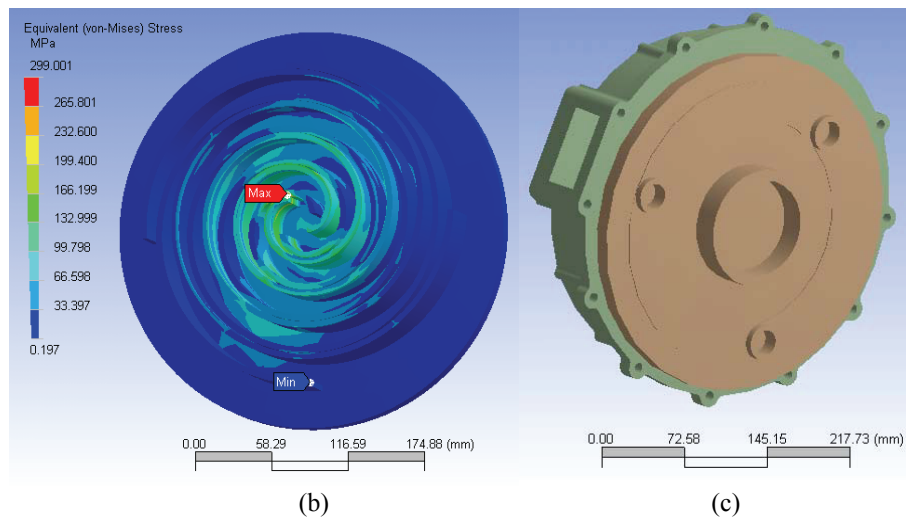


Figure9 Mises Stress and Deformation Distribution of Scrolls Engaged with Each Other
in the Minimum Gap Situation ($\delta_a = 0mm$; $\delta_r = 0mm$)

(a) Total Deformation Distribution (b) Mises Stress Distribution (c) Scrolls Engaged with Each Other

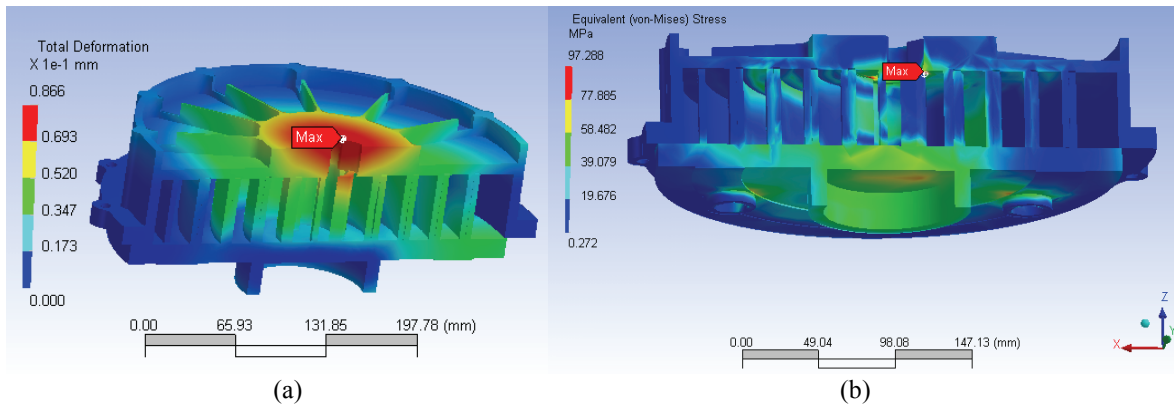
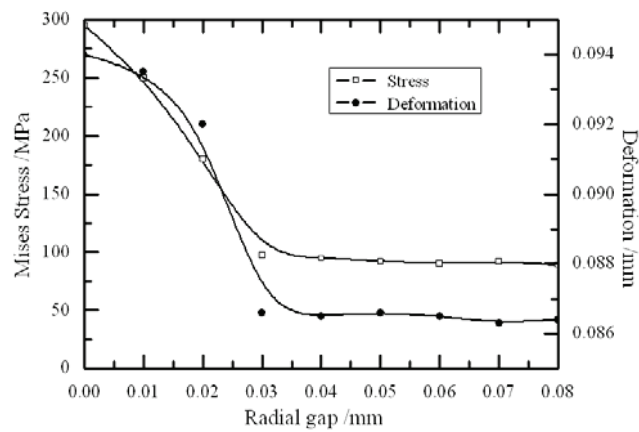
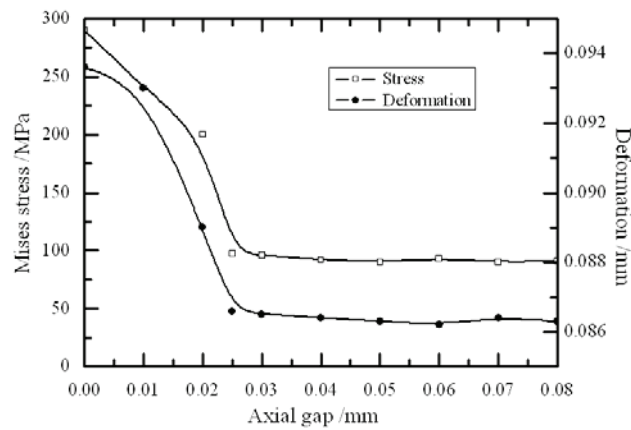


Figure10 Mises Stress and Deformation Distribution of Scrolls Engaged with Each Other in the Critical Gap Situation ($\delta_a = 0.025\text{mm}$; $\delta_r = 0.03\text{mm}$)

(a) Total Deformation Distribution (b) Mises Stress Distribution



(a)



(b)

Figure11 Axial and Radial Gap VS the Maximum Mises Stress and Deformation of Scrolls Engaged with Each Other

(a) Radial Gap VS the Maximum Mises Stress and Deformation ($\delta_a = 0.025\text{mm}$)

(b) Axial Gap VS the Maximum Mises Stress and Deformation ($\delta_r = 0.03\text{mm}$)

